Environmental Monitors on Lobster Traps
Phase I: Temperature

Final Report to Northeast Consortium

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Abstract

As our nation prepares to implement a coast-wide ocean observing system, the eMOLT program provides an example of how local fishermen can help. Beginning in the Spring of 2001, sixty-five New England lobstermen have now deployed miniature temperature sensors on their traps at fixed locations and depths. Nearly 2 million hourly records of bottom temperature (0.2 degC accuracy) have now been recorded at a total of 245 sites ranging from the Grand Manan Channel to the Hudson Canyon in water depths of 1 to 300 meters. With the help of the various lobstermen associations (Downeast, Maine, Massachusetts, and Atlantic Offshore), data is downloaded every 6 to 12 months, plotted, archived, and web-served. While efforts are now underway to develop and deploy a set of "realtime" probes that will transmit up-to-date readings via satellite, it is expected that the less-costly, internally-recording probes will be maintained for years to come.

Records thus far have documented a wide range of variability. The **inter-annual** signal can be several degrees in some locations and seasons. The spring of 2002, for example, was significantly warmer at nearly all sites relative to other years. The **seasonal** cycles at each location can be drastically different. The fall overturn in Mass Bay, for example, occurs each year but the timing of this event can vary year-to-year from late August through early November. The **tidal** variation at many sites can be several degC and, in a few cases, more than 10 degC such that the presence (or absence) of thermal fronts can be easily detected.

A few participants have submitted haul counts of lobster (*i.e.*, catch) along with their temperature records. This data provides an opportunity to correlate the two variables in some locations. While very little has been concluded as yet concerning lobster behavior in response to temperature change, some interesting hypothesis have been developed. Mutually-collected data provides fodder for discussion between fishermen and scientists which, in turn, provides a conduit for better personal relationships.

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Introduction[1]

A network of strategically-located bottom temperature records in the Gulf of Maine/Georges Bank region would make an important contribution to operational oceanography. Recent numerical modeling efforts (Namie et al, 1996; Chen, 1995; Brown and Bub, 2000; Xue et al, 2000; Brooks, 1994; Signell, R.P. et al., 2000, He et al, 2005) to characterize the important physical processes of our coastal ocean are limited by a lack of near-bottom data for both initializing and validating simulations. Just as weather forecast modelers need a large expanse of data to initialize and assimilate the atmosphere, oceanographers will require continuous readings of temperature to monitor the mixing and advection of multiple source waters.

Recent observational programs like GLOBEC and ECOHAB have documented numerous "anomalous" events due to unexpected displacements of water mass boundaries. These "events" are episodic in nature. In the case of Georges bank (Manning et al, 2001; Bisagni et al, 1996) the episodic residency of two water masses (Gulf Stream and Greenland ice melt origins, respectively) results in very dynamic living conditions for organisms residing in this area. In the case of the Maine coast (Lynch, et al. 1997, Mountain and Manning, 1994; Schofield et al., 1998) variability is often related to a combination of upwelling/downwelling, river runoff, and influx of remote source waters. A long-term inexpensive monitoring strategy is necessary to document the frequency and extent of these events. While satellite imagery has provided a mechanism to describe the spatial variability and complexity of the thermal structure in our coastal waters it is hampered by clouds and fog in these areas and only provides a temperature associated with the very skin of the ocean. Deep near-bottom temperature has less bias associated with short term processes making it better suited as an indicator of longer-term climate variability than the sea-surface value.

Understanding the relationship between bottom water temperature and behavior of *Homarus americanus* off the coast of New England may be an important by product of this study. What are the scales of variability and what degree of variability can initiate a migration of the lobster population? Given the economic importance of *Homarus americanus*, very little seems to be known about what factors govern the distribution and migration of the New England stock. As reviewed by Factor (1995), there are only a few studies in the past decades that have specifically examined the dynamics of lobster habitats in the vicinity of the shelf edge. References are made to Cooper and Uzmann (1980), for example, who demonstrated an on-shore migration to warmer waters in the summertime after releasing several thousand tagged lobsters and recapturing 12%. These studies were conducted nearly thirty years ago. The hydrographic data that was used to correlate with lobster migration was a monthly-mean bottom temperature record averaged over a few decades (Colton and Stoddard, 1973). They conclude that the lobster migration maintains a 8-14 ^{o}C thermal regime. Can we resolve that range more

[1] Much of this section and the following "project objectives" section is taken near-verbatim from the original proposal written in early 2000.

accurately? Other investigations (like Ennis 1984 off Newfoundland) demonstrate on-off shore movements as an avoidance of wave-induced disturbances.

Much of the migration apparently is driven by the animal's life history and reproductive cycle. Peak hatching of stage 1 larvae occur at temperatures in the vicinity of 11-13.6^{o} C bottom water (Fogarty and Lawton, 1983) resulting in planktonic surface concentrations in May through September. Harding et al. (1983) noted a 12.5^{o} C surface temperature associated with the first arrival of stage 1 and other, more detailed, conclusions in all areas of its range. Larval release occurs in burst of up to 2000 individuals and results in swarms within the top two centimeters of the water column (Herrick, 1895). After about four molting cycles/stages the animal will reach its juvenile stage with carapace length increasing from 2-5mm. The rate of growth depends largely on temperature (faster in warm conditions) but this transformation generally occurs in less than a few months. MacKenzie (1988), for example, finds that stage 5 lobsters reared at 15^{o} and 18^{o} C had significantly greater dry weights and carapace lengths than those reared at 10^{o} , 12^{o} , and 22^{o}C. In the wild environment, the highest survival rate is associated with rapidly increasing surface temperatures which provide a relative short planktonic period of life. While "temperature is the most important factor affecting growth and survival of larval and post-larval lobsters" (Factor, 1995), high salinities >30 PSU may be detrimental to lobsters in warm >20^{o}C water (Sastry and Vargo, 1977). The optimal salinity reported by Templeton (1936) is 30-31 PSU. Post-larval lobsters, however, have a tremendous swimming ability and are able to move to different environments with speeds of 15cm/s for up to five days resulting in 65 km excursions(Cobb et al, 1983).

What regulates the abundance and distribution of **adult** lobsters? Relationships of lobster concentrations to environmental factors cover a wide range of natural variability. Some reports such as Boudreau 1991, show relationships with windy conditions just after hatching and year class strength 8 years later. On the other hand strong stratification and thermocline trapping may expose post-larval lobsters to longer periods of predation. The dominant factor is not clear. Lobsters can sustain a wide range of temperatures -1 to 30 ^{o} C and abrupt changes of 16 ^{o} C (Harding, 1992). The temporal variation of lobsters at a single location is governed by the degree of movement. Movements come in the form of migrations, homing, and nomadism. Much of the information on migration of offshore lobsters comes from Cooper and Uzmann reports on tagging experiments in, for example, 1971 and 1980. The overwintering strategy offshore tends to keep the animals in preferred temperature range of 8-14 ^{o}C. Uzmann et al. 1977 estimates migratory speeds of these lobsters of 7.4-9.3 km/day. While there is little doubt that the animals migrate great distances, the unknown parameter is what triggers the initial response.

The multiple scales of variability in both time and space necessitate a multi-year data set to make conclusive arguments. Given the relatively minor expense of the monitoring equipment relative to traditional oceanographic moorings, a multi-year deployment was feasible. The intent of this project however, was to simply introduce lobstermen to the temperature probe technology so that over the course of a few years they become familiar with using the probes and comfortable with the operation. In the years now subsequent to the funded period, nearly all fishermen continue to use probes and contribute to an ongoing data pool.

Project Objectives and Scientific Hypotheses

Lobster catch off the coast of northern New England has reached historically high levels in recent years. If and when it begins to fall in the near future questions will undoubtedly arise on the role of the environment and long term climatic changes. The discussion is already underway, in fact, along the Southern New England coast. The absolute causes of lobsters demise in that area is still under debate (Allen, 2003). Of particular concern is the potential effect of long-term climatic change. How will the lobster population respond to an apparent warming of the environment over a long time scale? Given a confounding influx of cold ice melt from the north, it is possible that this large scale weather pattern is affecting the northern New England region less so than the southern. If so, what are the transport mechanisms providing this Canadian source water to the Gulf of Maine and how quickly do particles move along the coast? The North Atlantic Oscillation complicates this long term trend as it occasionally provides relatively warmer water masses to the Gulf of Maine and can thereby alter not only the temperature and salinity throughout the region (at depth in particular) but the circulation pattern as well. These large scale, long-term questions can only be answered by Gulf-wide, multi-year, low-cost, collaborative studies with the help of fishermen.

What is the long-term future of our coastal waterways? Since there will undoubtedly be more calls for offshore industrial structures such as wind towers and underwater tidal current generators, we need to assess the environmental impacts and feasibility of each proposal in specific areas of the coastal zone. Do we have enough understanding of the residual currents in each location and the degree of variability expected in those locations? Studies of this type need years of data to develop a statistical understanding of various dynamics. A long term (multi-year) monitoring strategy as we are testing with this experiment may provide a low-cost solution.

Motivation/History

For several months in 1995, a newly-developed VEMCO temperature probe was attached to the GLOBEC mooring "ST2" on the Southern Flank of Georges Bank. The unit obtained hourly temperatures for the entire deployment. The record compared extremely well with that of the more expensive traditional model attached along side. Given the success of this new compact probe (costing less than 10% of the traditional probe), the possibility of cost effective monitoring was obvious. Soon after this test of the VEMCO probes, they were deployed in an ongoing water temperature monitoring project in Woods Hole Harbor.

In 1996 and 1997, with cooperation of three local lobstermen (Marc Palombo, Bob Colbert, and Bro Cote), bottom water temperatures were successfully recorded on the southern edge of Georges Bank over periods of several months. This pilot experiment was conducted to assess the interest of the fishermen and test the feasibility of such a monitoring strategy. The initial results were very encouraging. The concept of a cost effective partnership with local lobstermen and application of small temperature probe technology was demonstrated.

Despite the limited amount of data collected in these early years, several significant oceanographic events were documented. It became obvious that multiple scales of variability could be captured (see Figure 1) including effects of hurricanes, tides, Gulf Stream Rings, and seasonal cycles.

It should be noted that, while this report covers the first phase of the eMOLT project (still ongoing at the time of this writing and is expected to continue for years to come), there were subsequent phases II, III, and IV. The Final Reports for these subsequent phases are available on the eMOLT "Updates/Reports" page. They describe efforts to monitor salinity, implement electronic logbooks, and build/deploy satellite tracked drifters, respectively.

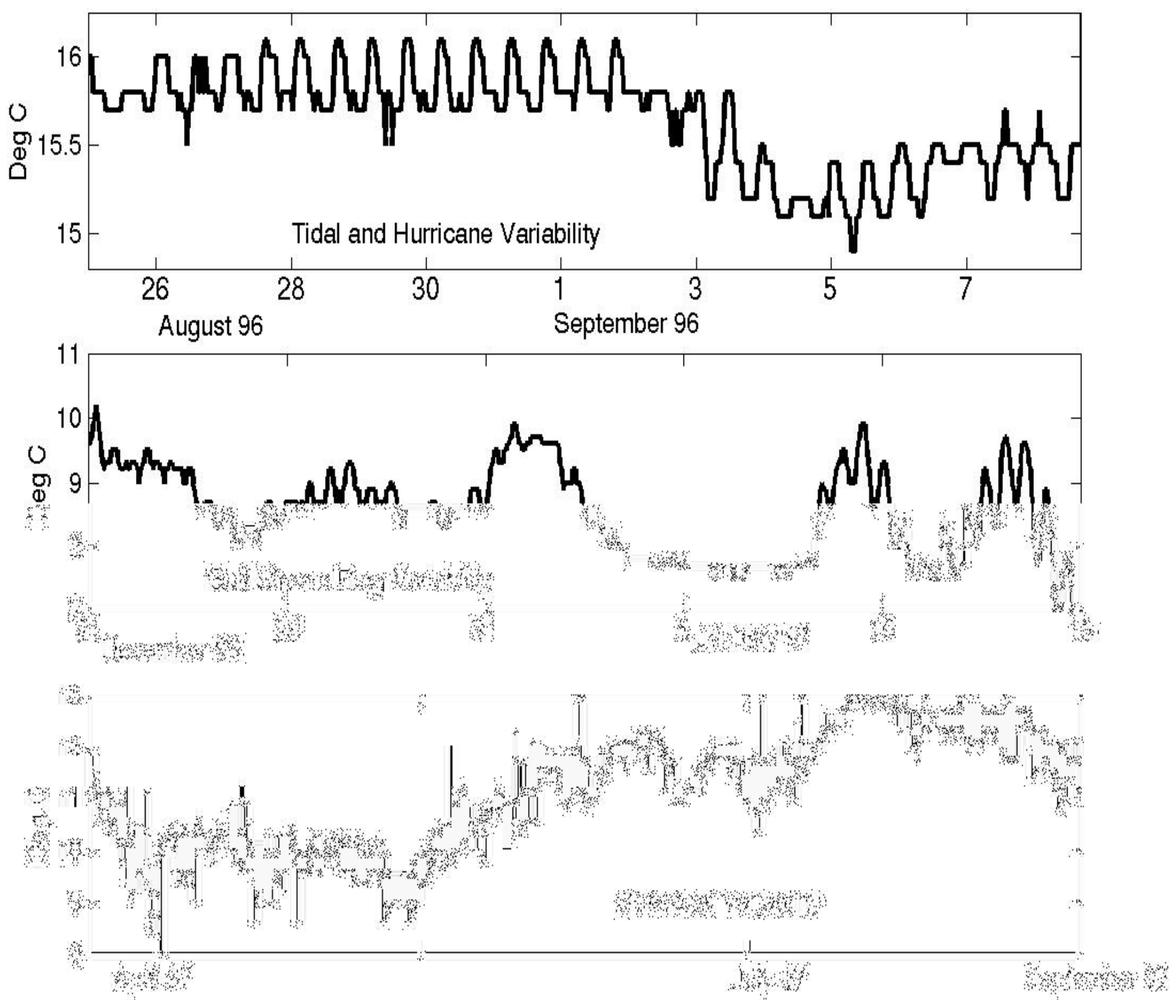

Figure 1. Pilot experiment results from 1996 and 1997. The three records, obtained by three different lobstermen, recorded three different scales of variability.

Participants

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While the primary administrators are listed above, many other people were involved with the project. The lobstermen involved with temperature probe deployments are listed in Appendix I. All are acknowledged for their efforts.

Methods

The methodology is simple. Temperature probes are bought and distributed by the Lobsterman Associations around New England. A few individuals from each association are trained by the scientific party to initialize probes and download data. Both the temperature data and the mooring logs are emailed at least once per year to the scientific party.

Probes

Figure 3. VEMCO Minilog reader (left) and probe (right).

Figure 2. ONSET TidBit probe attached to a trap on the dock in Woods Hole. Normally the probe is attached safely inside the trap bridge.

As noted in the history section above, the eMOLT project began with using the VEMCO Minilog8-TR probes (Fig. 2). These are made in Halifax, Nova Scotia and were specifically designed with fishermen in mind. We most often use the unit designed for -4 to 20 degC in order to get a 0.1 degC accuracy. Other units designed for -5 to 35 degC are often used for the very shallow (or deep offshore) sites with closer to 0.2 degC accuracy. However, when we started the project in earnest in 2001, we made bulk purchases of >100 ONSET Tidbit temperature probes (Fig. 3) which had similar cost and accuracy and had the advantage of being locally made in Onset, Massachusetts. After some discussions with their engineers, we were able to contract them to make a unit specifically designed for our purposes (cold waters of the Gulf of Maine) which resulted in a probe with accuracy <0.1 degC. These probes have performed well and, in most cases, are still in operation at the time of this writing although may be soon reaching their battery life. The one major problem we have with these probes is the loss of the infrared communication terminals. These small plastic "nubs" are evidently crushed, in some cases, by lobster claws but the dominant cause for the damage has yet to be determined. A large portion of the damaged units were returned from the Atlantic Offshore Lobstermen (AOLA) which leads to the conclusion that the excess pressure in their deep water environment may be partially the problem. In any case, beginning in 2004 we returned to using the VEMCO probes. [2]

In 2003, a special VEMCO TRP-FP probe was purchased with a fast-response temperature and pressure sensor. The purpose of this experimental probe was to demonstrate the possibility of fishermen obtaining vertical profiles through the water column. While the probe was never used operationally, it was tested. The results of experiments with this probe off two different fishing vessels are reported below.

Early in the eMOLT years, a proposal was submitted to NOAA's Small Business Initiative Research program to have a "realtime" temperature probe developed for lobstermen. More than a dozen companies responded with proposals and, after a lengthy review period, the Advanced Design Consultants Inc. of Lansing, New York was awarded the grant to develop a probe that wirelessly transmits data to a handheld unit in the wheelhouse. When the probe is hauled to the surface, it senses zero pressure and transmits data since the last haul operation. In early 2005, the probe was tested by two local lobstermen, Phil Mason and John Carver, in Mass Bay but, after two weeks at depth, failed to transmit. The unit is still underdevelopment at the time of this writing. ADC Inc has obtained phase II SBIR funding to investigate uplinking the data from the handheld (or the sensor unit itself) to a satellite network.

Probe Comparisons and Calibrations

A series of tests and evaluations of different probes were conducted over the years in four different modes: off the dock, in the field, in controlled-environment tanks, and in ice baths. These involved submersing multiple probes side-by-side for varying lengths of time (typically overnight at least) to document potential biases between probes and probe manufacturers. The ice-bath tests have been conducted several times over the project years whenever a large quantity of probes is collected at once. This occurs, for example, nearly each year at both the Mass Lobstermen Weekend and the Maine Fishermen's Forum. While the exact protocol to conduct this ice bath experiment changed over the years (after multiple communications with the ONSET manufacturers on the best way to conduct accuracy checks), the routine is fairly stable. The probes are submersed in a half-ice and half-water solution overnight so as to allow the environment to stabilize near zero degC and then the vessel was allowed to sit in room temperature for several hours. This allows the environment to span the range normally exposed to in the Gulf of Maine and provides a means to check biases at multiple temperature zones (since the probes are often engineered for specific ranges). In the first few attempts at this procedure, biases of close to 1.0 degC were obtained but much of that value was apparently due to the ice bath being not exactly a controlled environment. A crushed-ice bath is apparently more accurate that an ice-cubed bath. An insulated and refrigerated vessel, for example, is apparently more accurate than a plastic bowl. Given these modifications in ice-bath protocol, documented biases have been reduced to acceptable levels (~0.2 degC). A summary of these comparisons and calibrations is presented in the results section below.

[2] At the time of this writing, Feb 2006 we are experimenting with a set of 60 LOTEK LTD 1100 tags that have been provided to us by Dr. Gary Shepard (NOAA/NEFSC).

Mooring Log/Documentation Protocol

The majority of the participants simply provide the site information (e.g. mooring logs of the position and date/time of deployment and recovery) but some opt to keep a spreadsheet of haul (i.e. catch). Using whatever spreadsheet software the lobstermen (or administrator) is familiar with, the following minimum set of information is recorded: Site, Serial number of probe, Latitude, Longitude, Time, Water depth, #traps/haul, and #lbs kept/haul. In many cases the #shorts and the #eggers are kept as well. The protocol for these logs are posted on web served documents at emolt.org. Since the eMOLT project is no longer funded, the association representatives are no longer responsible for entering catch data into electronic spreadsheets. The participants are now told that if they still want to provide catch data (in order to see their catch plotted along with temperature records) they are required to enter the information electronically themselves and mail it directly to the scientific party. A sample logsheet is attached in Appendix I along with the instructions given for filling it out. The logsheet design continues to evolve.

During the Phase II of the eMOLT project, an electronic logbook, know as the "Thistle Box", was used by several participants. This unit was somewhat successful, especially in the case of the Atlantic Offshore Lobsterman, in collecting GPS position data along with user-entered catch data. The unit eventually failed in 2004, however, due to problems with user-support, occasionally having shipboard electrical-interference trouble, and the $30/mth service fee being, in some cases, not worth it. The company eventually went out of business. Nevertheless, the unit did show promise in many cases in collecting a large amount of site-specific data. Nearly 1000 hauls are now documented in the emolt_set database, a good portion of which resulted from this system. The scientific party was able to download data from participants through the Thistle web site, parse out the information needed (using a perl routine), plot both position and catch data (using MATLAB routine), and archive the data (using ORACLE routine).

Database Procedures

The master eMOLT database resides on a secure machine at the Northeast Fisheries Science Center in Woods Hole in the form of four ORACLE tables: emolt_site, emolt_people, emolt_sensor, and emolt_set. Each time a temperature record is submitted to the various lobster association representatives, the individual responsible runs the commercial software ("Boxcar" in the case of ONSET probes and "Minilog" in the case of VEMCO probes). The binary data file is given a particular 6-digit name including a four digit site code followed by a two digit integer representing the consecutive deployments conducted at that site. This file is then emailed to Woods Hole where the scientific party then conducts a series of processing steps:

1. The same commercial software, takes the binary data and exports to ascii
2. MATLAB code "emolt.m" parses the ascii file and conducts the following:
    a. plots raw data and asks user to click on start and stop times (i.e. specify time period the probe was actually in the water)
    b. eliminates extraneous data points likely resulting from those times the lobsterman is hauling the trap to the surface by conducting a range and

delta check (Note: The criteria by default looks for temperatures in reasonable range 20-80 degF and 1.5 degF hourly variations but these criteria are often adjusted, for example, in regions where the hourly change in temperature often exceeds 1.5 degF. The objective graphic data editing procedure is repeated iteratively until obvious spikes are removed.)

c. for cases where salinity and pressure are included, these variables are plotted and cleaned as well

d. final plots (Figures 4 and 8) are made that includes a view of both observed raw data, the processed hourly data, and the daily average in jpeg, png, postscript, and fig formats. (Note: The jpeg and png are available for posting on the web, the postscript format is a better quality format for printing, and the "fig" format is an object oriented MATLAB file that can be easily modified.)

e. finally, an ascii file containing clean temperature data (including the probes serial number, site code, and estimate of both probe depth and water column depth) is output

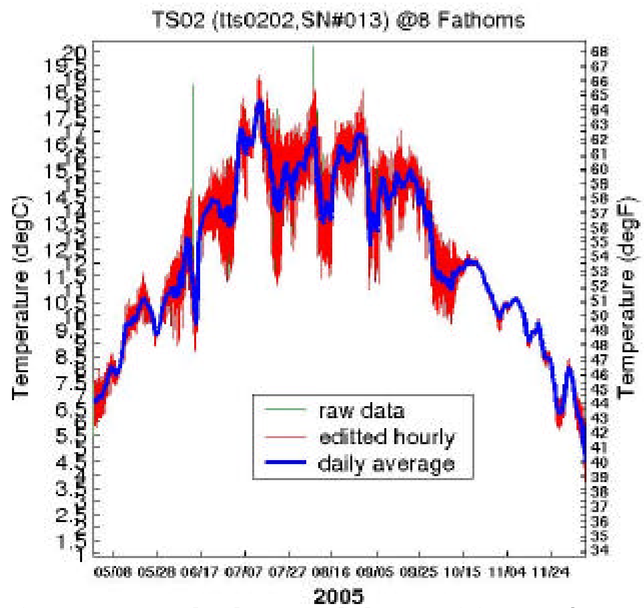


Figure 4. Example plot provided to participants after each deployement.

3. This cleaned data is loaded into the ORACLE emolt_sensor table where it is available through a variety of utilities depending on the users level of expertise:
   a. emolt.org website under "data access" via a cgi-script routine
   b. An OPeNDAP (Opensource Project for a Network Data Access Protocol) server at: http://gisweb.wh.whoi.edu:8080/dods/whoi

Website Organization

An extensive array of information is posted under the emolt.org webpage according to the following outline:

Figure 5. eMOLT logo.

- Overview
- What's New
  - Near-weekly updates on what is new in terms of eMOLT evolution, new data, most interesting findings, etc.
- Result to date
  - Drifter study
  - Temperature study
    - Direct links to participant's individual web pages
    - Interactive eMOLT Mapping Utility (still under development)
    - GoMOOS-provided map of clickable links to various lobster zones along the coast of Maine.
    - PowerPoint Presentations and Animations
  - Salinity study
- Data Access
- Updates/Reports
- Training Sessions/Meetings

Other links are provided including those to proposal documents, manuals for both participants and administrators, eMOLT in the news articles, contact information (includes a pull-down list of all participants), a gallery of eMOLT photographs, and several related links. The manual for administrators includes, for example, information on ordering and comparing probes. The manual for participants includes, for example, the protocol for documenting the deployments.

Results and conclusions

1. Sites Occupied

At the time of this writing (Jan 2006), there are 115 eMOLT temperature-monitoring sites that span multiple years. Including all deployments with shorter records, there are well over 200 sites. The positions of multi-year sites are plotted in Figure 6 color-coded by lobstermen association. The green dots are associated with "other" institutions such as Mass Division of Marine Fisheries, Maine Division of Marine Resources, the Rhode Island Lobsterman Association, and others who have also contributed to the database. The statistics of record lengths are presented graphically in Figure 7.

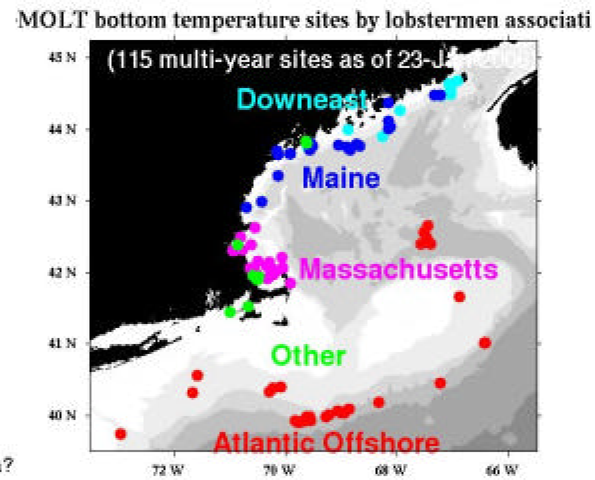


Figure 6. Multi-year bottom-temperature sites color-coded according to association.

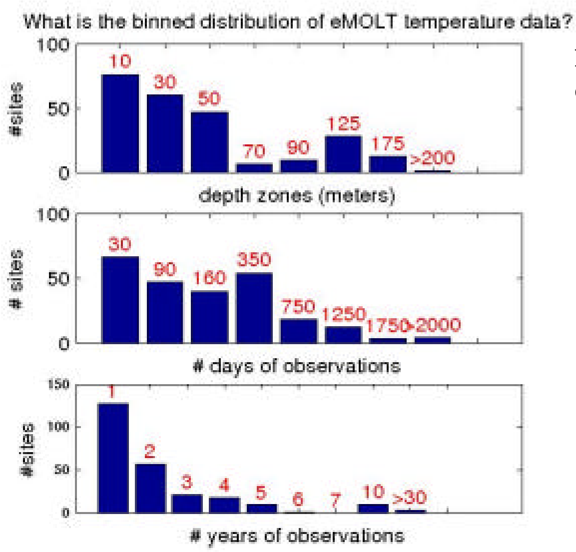


Figure 7. Distribution of sites according to depth zones (top), # of days recorded (middle), and years recorded (bottom).

The top panel illustrates the distribution of sites with respect to water depth with the majority falling in the bins representing 50 meters or less. The small peak at 125 meters is due to contributions from AOLA on the shelf edge. The second panel illustrates the distribution of temperature records with respect to the number of days per time series. While the average length of hourly records at a single site currently averages about a year (i.e. 365 days), there are many shorter records and a lesser amount of records with over 365 days worth. Some of these sites with multiple years of record are described below. A few sites stored in the eMOLT database with >30 years of observations include, for example the dockside series from Woods Hole and Boothbay.

2. Interannual variability

Now that each association has several sites with multiple years of time series, the degree of interannual variability can be addressed. Seasonal cycles can be derived and anomalies calculated. In the case of David Johnson (Figure 8) and many others, the year 2002 stands out as an anomalously warm year. Where 2001 might be considered a "normal" year 2003-2004 are relatively cold at most sites especially during the Winter-Spring season. Late 2005 appears to be warm. Figure 9-12 includes results from DELA, MaLA, AOLA, and MeLA respectively. In order to see the anomalies more clearly, seasonal cycles can be removed from the data as in Figure 13 where several participants in Maine have contributed multiple years .

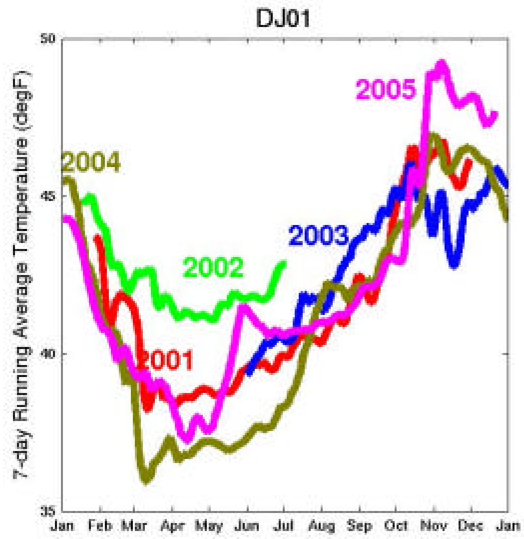


Figure 8. Another example of the type of plot provided to participants after each deployment period.

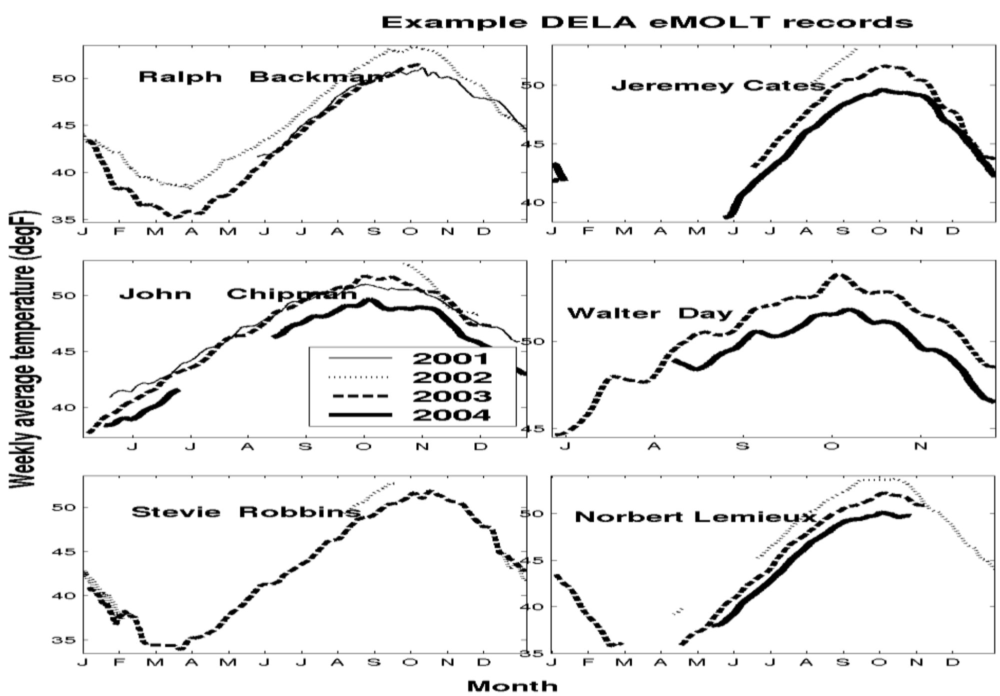


Figure 9. Examples of Downeast Lobstermen's contributions, those with multiple years of observations.

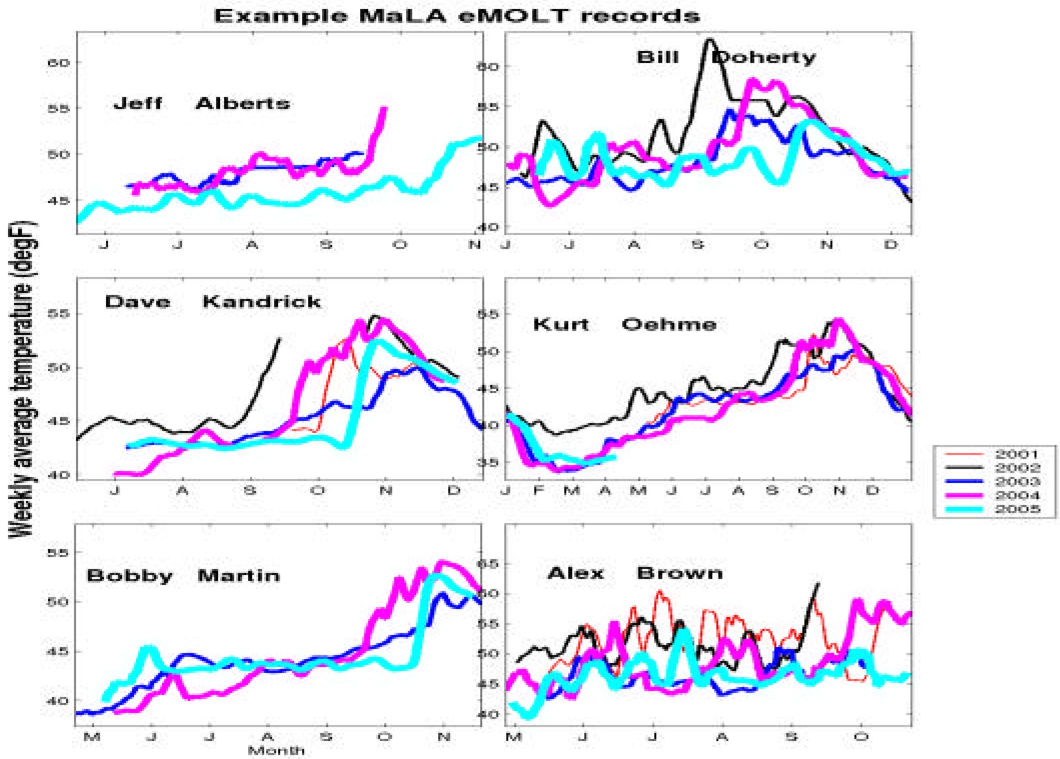


Figure 10. Mass Lobstermen's lead participants with multiple years of observations documenting, among other things, the fall turnover in Mass Bay.

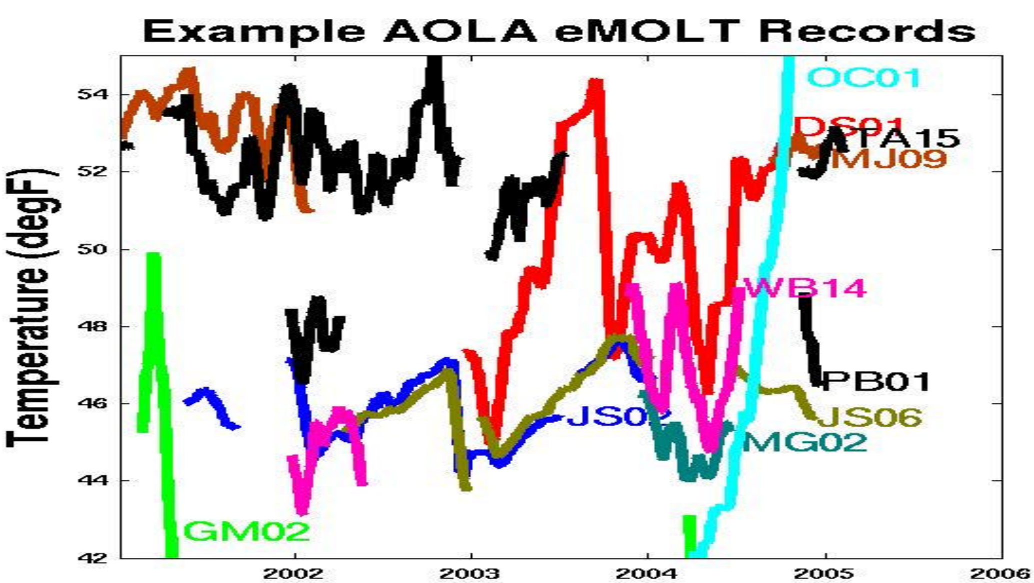


Figure 11. Atlantic Offshore observations of bottom-temperature variability along the edge of the Southern New England Shelf. With little or no seasonal cycle, most variability is associated with offshore eddy activity.

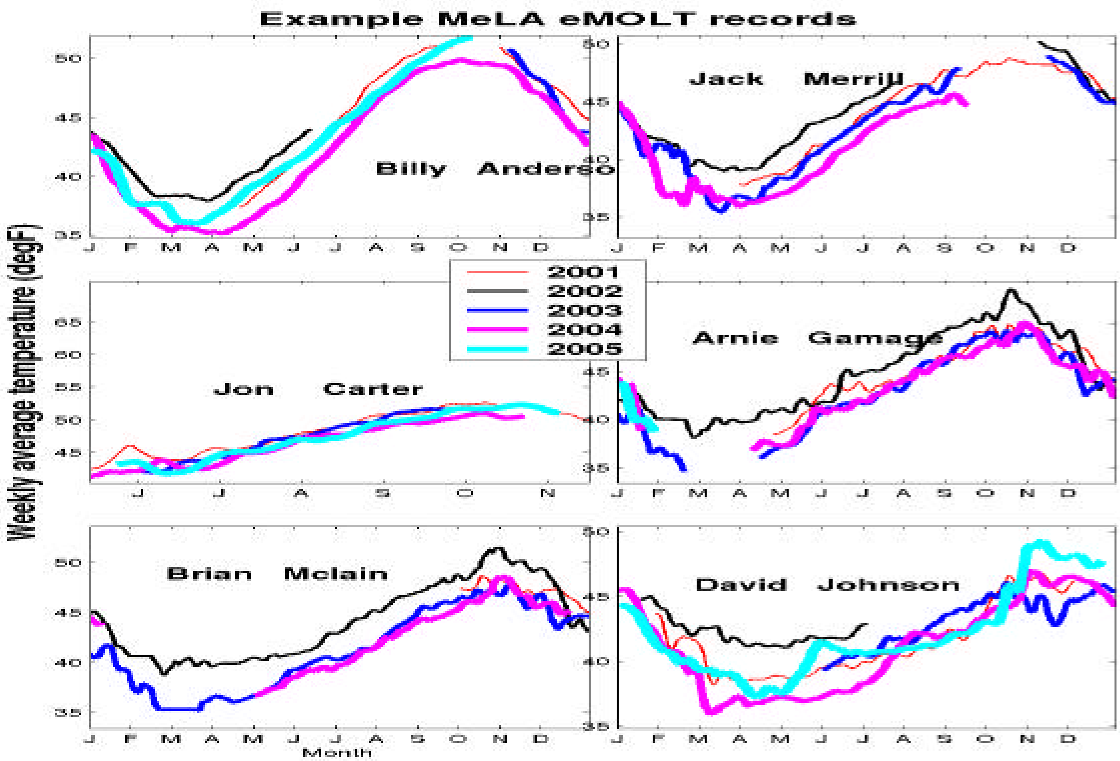


Figure 13. Selection of Maine Lobstermen who have recorded multiple years of data from single locations.

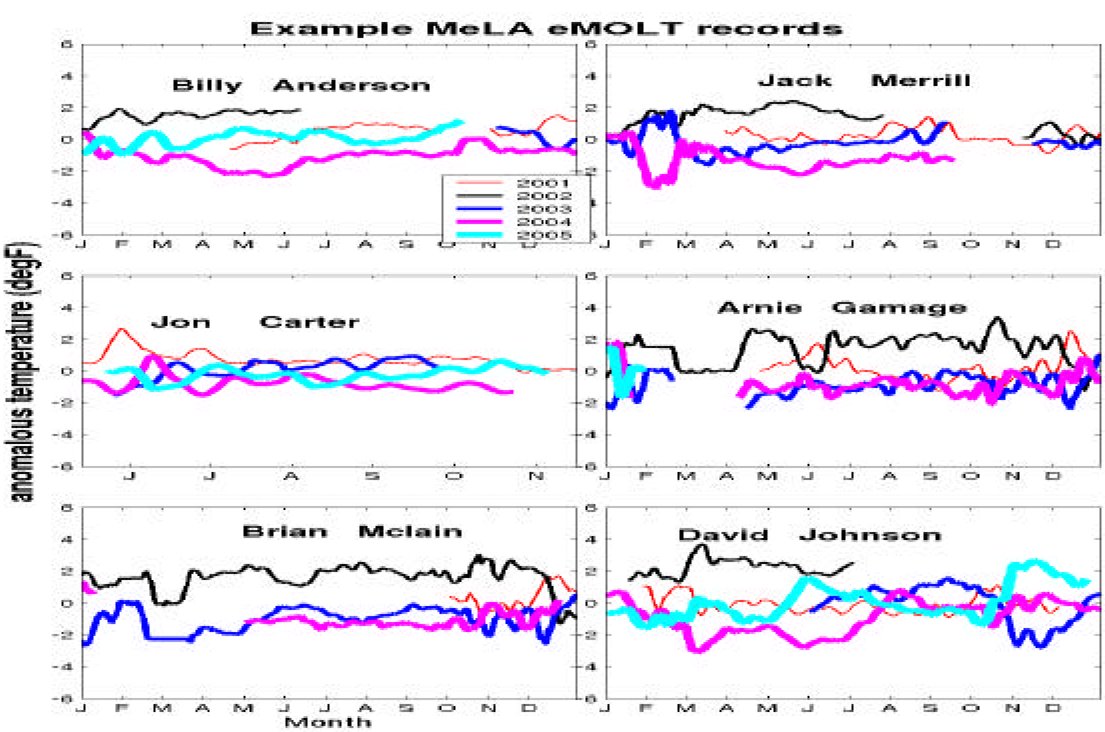


Figure 12. Example of Maine Lobstermen's anomalous temperatures after having removed the seasonal cycle (yearday averages).

3. Wind-driven events

It is interesting to investigate the mechanisms of rapid temperature change (i.e. event-driven variability). This type of bottom-temperature analysis was not possible in the Gulf of Maine to any large extent before the eMOLT records began to reveal the dramatic effects of, for example, Northeasters. The occasional shipboard observations of bottom-temperature from profiles can not document the quickness of the ocean's response to wind. The phenomenon is especially clear in Mass Bay where the strongly stratified water column is suddenly disturbed sometime between early September and early November by burst of Northeasterlies. This process is illustrated in Figure 14, for example, where the "northward" component of the wind suddenly shifts to negative (i.e. wind becomes southward) in early October 2005. Even though the surface water (as observed at the GoMOOS buoy A nearby) registers cooling water, the bottom water as measured on Dave Kendrick's trap at 40 meters depth rapidly increases by several degrees. This event is shown in more detail in Figure 15, where bottom temperature (left axis) is overlaid on wind (right axis). The bold blue lines represent periods when the wind out of the north exceeds 8kts as occurred, for example, in early October. This short wind event was enough to turn the bay over such that the warm surface water reached the bottom and increased the temperature more than 10 degrees

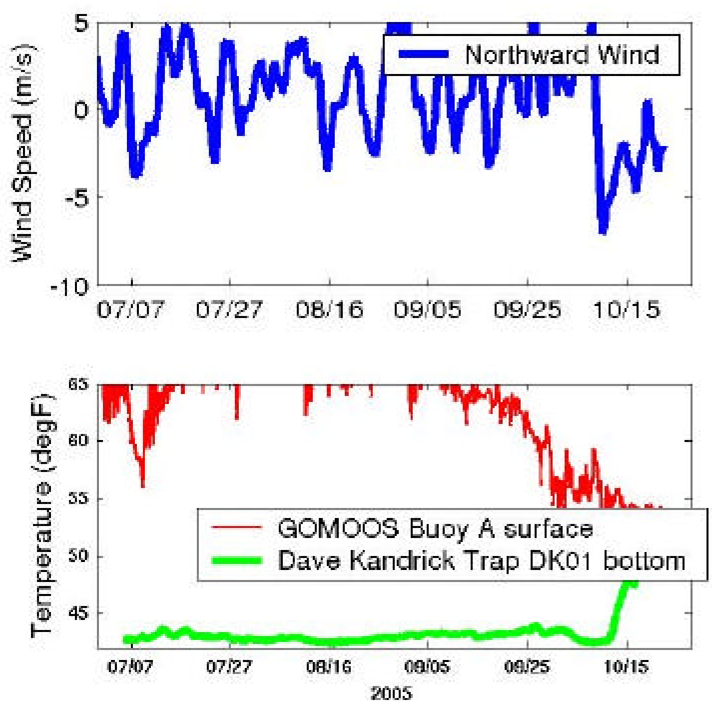


Figure 14. Example of wind-driven overturns that occur in Mass Bay each fall with the wind record (top panel) taken from GoMOOS Buoy A. Where the surface layer temperature (red bottom panel) the bottom-temperature at 40 meters (green) is cooling.

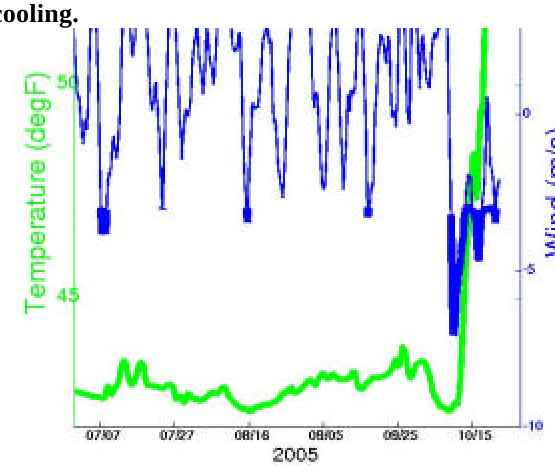


Figure 15. Close-up of the event described in previous figure. The bold blue represents period of strong (>3.5 meters/second) wind blowing from the north.

farenheight. While lobstermen are well aware of this annual event, the eMOLT records have now documented it for multiple years. A similar event happens each year but the timing of the event changes from year to year. Another case is depicted in Figure 16, showing a series of less-intense step-wise turnovers at Alex Brown's site AB01.

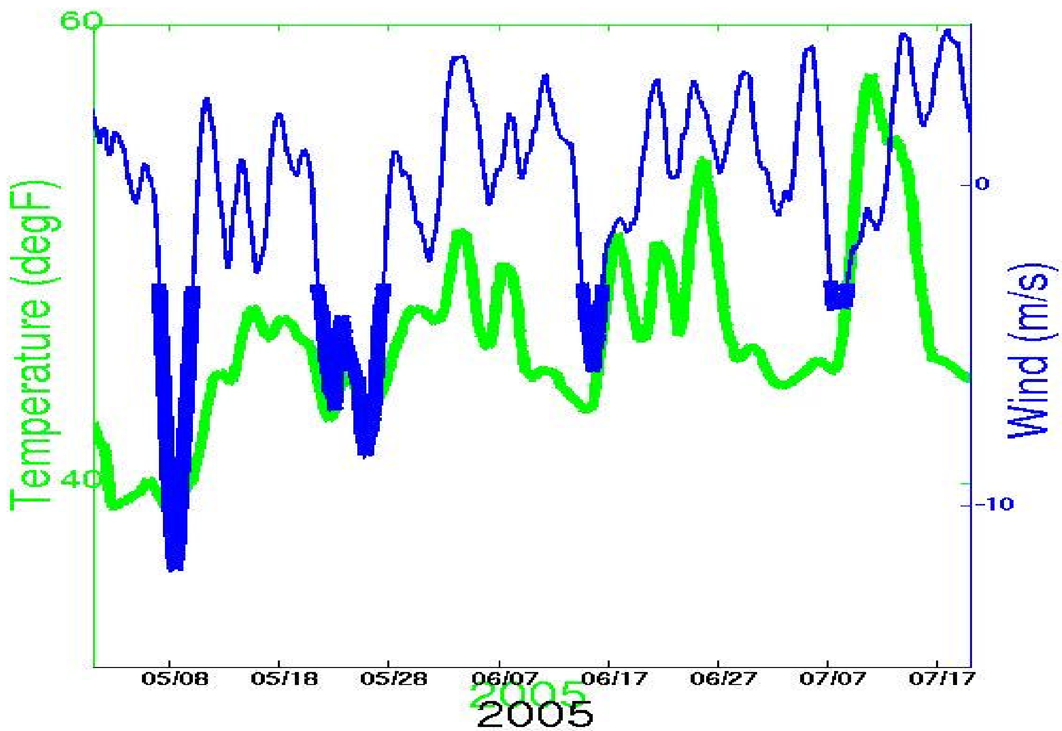


Figure 16. Example of step-wise, wind-driven warming of the bottom water (contribution by Provincetown's Alex Brown) on the east side of Mass Bay. The northward component of the wind is plotted so that negative values represent wind "from" the north.

4. Gulf Stream ring-driven events

As depicted in the station plot above (Figure 6), several sites occupied by AOLA participants are located in the very dynamic shelf edge where cold/fresh Canadian source waters often collide with tropically Gulf Stream ring waters. As shown in Figure 17 below, these sites are often affected by the perturbations from Gulf Stream rings and, as in this 2002 case, the migration of the ring can be tracked from week to week in the eMOLT records (Figure 18). The ring affected Bob and Marc grounds nearly a month before seen by John's further to the west.

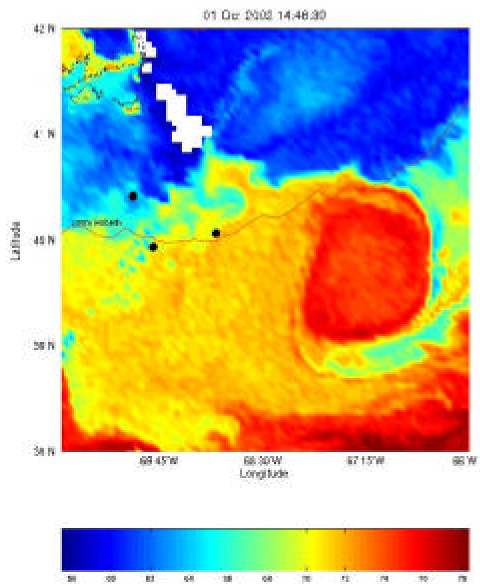


Figure 17. Seasurface temperature inferred from satellite showing the effects of a Gulf Stream Ring intruding into the Great South Channel. The three dots represent different fishermen. (Image data from URI/GSO).

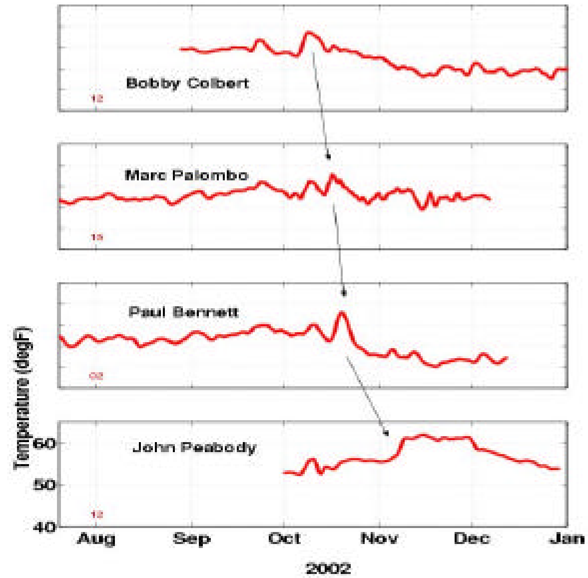


Figure 18. Illustration of propagating ring effects as they are encountered by various fishermen along the shelf edge.

5. Tidal variability

Finally, a shorter-term variability that is surprisingly strong in many records is due to the semi-diurnal tides. While this type of variability is present in nearly all the eMOLT records to some degree, the most dramatic cases occur where the traps are located in a region where the thermocline intersects the bottom. In the case of Alex Brown (Figure 19), for example, the temperature variations due to the tide can be as much as 12 degrees in three hours time. In Alex's case depicted here, there are subtidal variations due to wind-forcing (i.e. upwelling/downwelling) and result in several degree changes from week to week. It is interesting to note anecdotal information that commercial divers in the vicinity of Alex's fishing grounds, will often search out these areas of high thermal gradients in order to find the densest population of adult lobsters. This leads one to the hypothesis that perhaps lobsters do not seek an absolute temperature zone but rather a frontal region where, perhaps, there is a mechanism of convergence and food availability. As seen in both Figure 19 and especially in the case

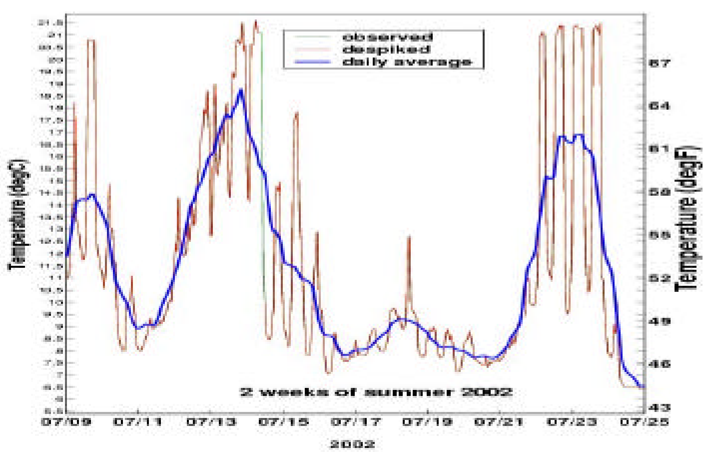


Figure 19. The most-extreme example of tidal variability as it effects the bottom temperature on the bay side of Truro, Ma. The thin, red lines denote the hourly values.

of Figure 20, the presence or absence of the thermocline in the vicinity of the trap can often be detected.

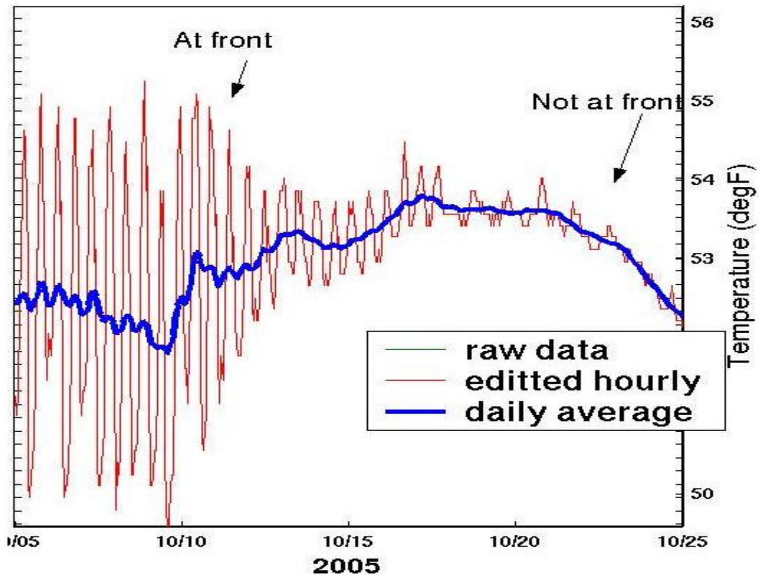


Figure 20. Example of detecting presence or absence of frontal gradients before and after a wind storm, respectively. Data contributed by Therese Sauvageau out of Beverly, Ma.

6. Fast-response-temperature sensor profile experiments

In addition to the standard internally-recording temperature probes, a few other devices were tested during the funded phases of eMOLT. As part of Phase I, VEMCO's fast-response temperature probe, for example, was evaluated. As noted in the methods above, one unit was purchased and used by multiple fishermen. While it did not get extensive use, the experiments conducted did demonstrate, at least, that is was possible for fishermen to deploy the unit in a "transect" mode in order to obtain cross-sectional images of the ocean temperature. After the unit was deployed by F/V Glenna and Jacob on Georges Bank in collaboration with the Fleet Link project (Figure 21), lobsterman Tom McVane then deployed the unit on multiple occasions in a transect off of Casco Bay (Figure 22). On some occasions Tom deployed the instrument on the bottom for multiple days and was able to monitor tidal height variations as depicted in Figure 23. The overall conclusion of experiments with this instrument is that it can be successfully deployed but the additionally deployment-logs needed to document the these deployments in "transect" mode requires considerable effort on the part of the

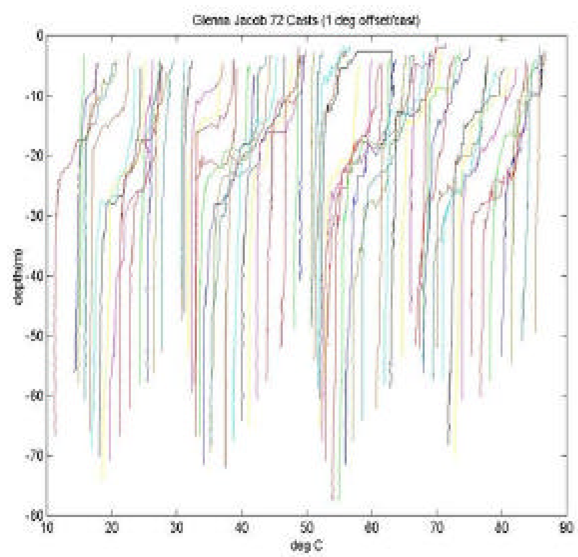


Figure 21. Example plots generated from the "fast-response temperature probe" after lending it to the Fleetlink program in 2002.

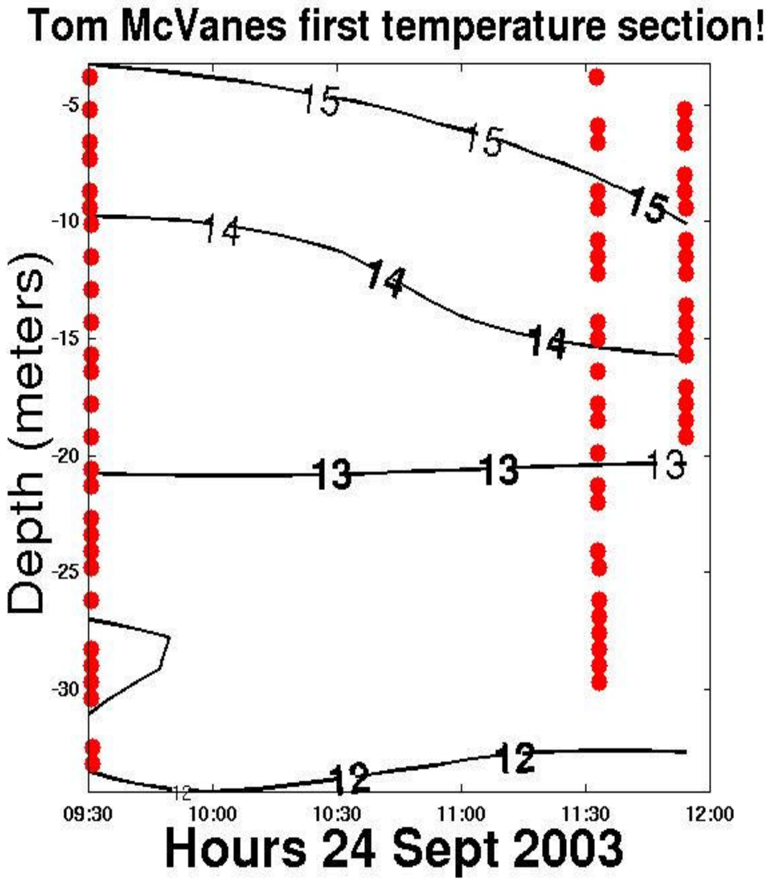


Figure 22. Example of cross-section obtained by lobsterman Tom McVane off Casco Bay in 2003 using the "fast-response" temperature probe.

participant. Given a small amount of funding needed to compensate participants for taking the time to logging position and depth with each cast, cross-shelf transects of the Maine Coastal Current, for example, could be obtained with regularity for very little cost in cases where lobsterman routinely steam perpendicular to the coast. A number of other lobstermen (Miller, Goldthwait, Thomas) expressed an interest deploying the instrument in this way, but given the effort to train these individuals and document the deployments, the instrument was stored until such time as funding allowed continued experimentation.

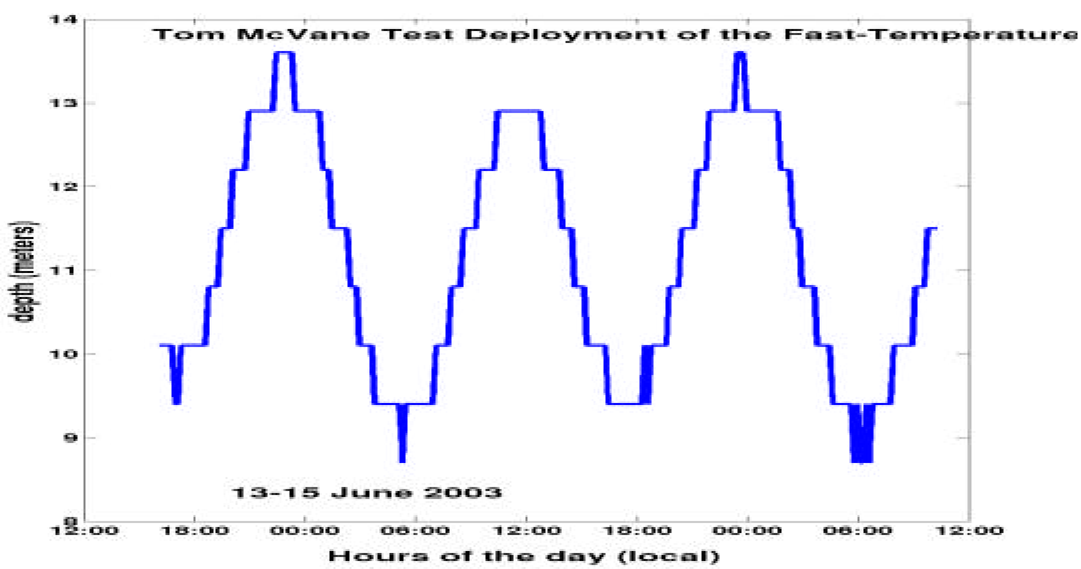


Figure 23. Example of water-depth records collecting using the "fast-response temperature" probe which has a pressure sensor as well. In this case, the 4 meter tidal variation in Casco Bay is recorded.

7. Pressure sensor experiments

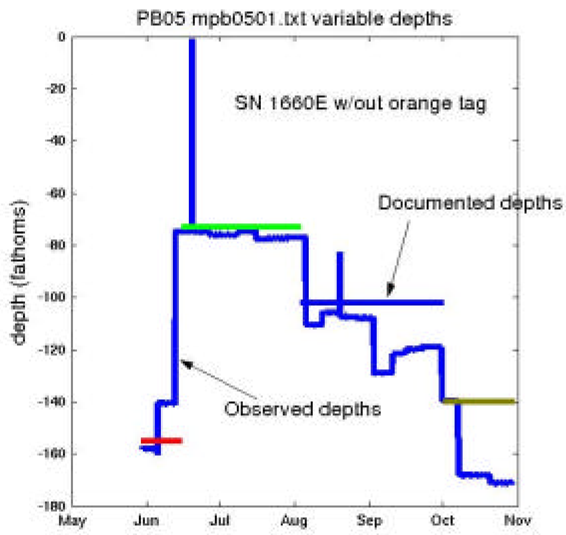


Figure 24. Example of the pressure (ie depth) sensor records along with those documented by AOLA participant Paul Bennett.

In recent years, several VEMCO temperature probes with pressure sensors were purchased and tested on the continental shelf edge sites. Given that AOLA lobstermen often fish on the steep embankment of the shelf, it is necessary to carefully document the probes variations in depth between hauls. While the participants attempt to maintain fix sites in these areas, the deep waters and strong currents in these areas prohibit them from doing so and the trap often lands in very different water depths from week to week. The interpretation and analysis of these records therefore becomes very difficult given the depth-dependent nature of temperature at the shelf-slope frontal zone. As denoted in Figure 24, for example, there is obvious discrepancies between observed and documented depths which is to be expected. As noted in the error analysis section below, this leads to the biggest uncertainty in eMOLT temperature records especially for those obtained along the shelf edge in years prior to 2004 when we started using the pressure sensors. In 2004 onward, the depth is recorded along with most AOLA records. So, while each site may have a nominal depth associated with it, the recorded depth is now stored with each hour.

8. Cross-shelf mooring array experiment

While each lobsterman typically deploys a single probe, some of the more curious of the participants have asked for multiple units in order to conduct their own experiments. Billy Anderson from Lubec, Maine is a case in point. In recent years, he has deployed a string of sensors with a surface and bottom unit on three separate moorings located in different water depths perpendicular to the shore. At the time of this writing the array is still in the water but it is hoped that by March 2006 these series will be recovered. At that time, a year-long, hour-by-hour animation of the cross-shelf temperature distribution can be generated. One scientific objective of this mini-experiment, aside from simply demonstrating that it can be done, is to detect the seasonality of the St. John river's effect on the downeast thermal regime. Can we document the effect of runoff events as they advect into the area? From the lobstermen's point-of-view, how far offshore is it necessary to fish in order to expose traps to a very different thermal regime?

9. Temperature vs catch investigation

As noted in the methods section above, a small portion of eMOLT participants record and submit their catch. These individuals understand that very little, if any, scientific conclusions can be obtained from a few years of limited haul data but it is nevertheless interesting to plot variations with haul counts with the temperature time series. The results of a few of these investigations are plotted in Figures 25-27 below. It is tempting to conjecture in the case of Bill Doherty's record, for example, that his catch rate dropped for a few weeks in September 2003 (Figure 25) when the temperature increased to greater than 52 degF. When Bills haul data is compiled over four years, the uppermost panel in Figure 26 indicates that the majority of his empty traps (indicated with black circles) occurred at temperatures below 48 degF.

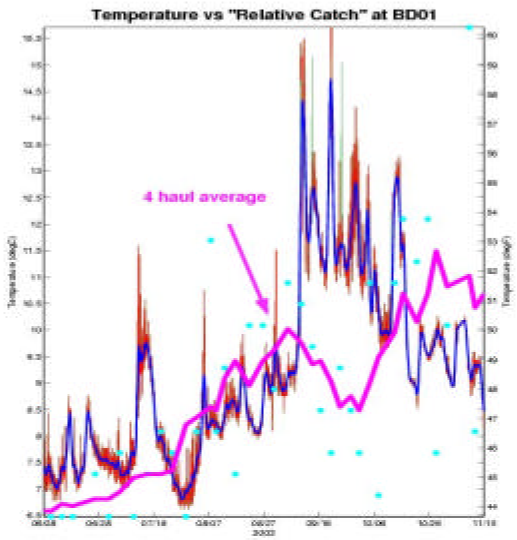


Figure 25. Example plot of "relative catch" available to participants who now submit haul data along with temperature records in electronic form. In Bill Doherty (Hingham, Ma) case shown here, very little can be concluded from this particular year's relationship.

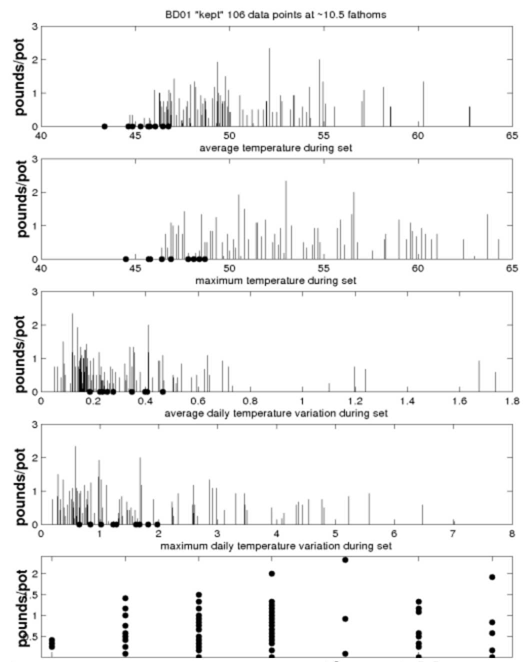


Figure 26. Attempts to quantify variables potentially related to catch.

In the case of Jack Merrill III, fishing in deep waters off the coast of Little Cranberry Isle in downeast Maine, haul counts indicate a peak near very late in the year just after the peak in temperature records (Figure 27). In addition to these examples, several other individuals have kept adequate records that allow a this type of preliminary investigation. Arnie Gamage, Brian Mclain, Bobby Nudd, Marc Palombo, Paul Bennett, Mark Wells, Alex Brown, and Bobby Colbert have also contributed haul data along with their temperature records. In unfunded phases of eMOLT in the future, participants are asked to submit haul data in electronic form.

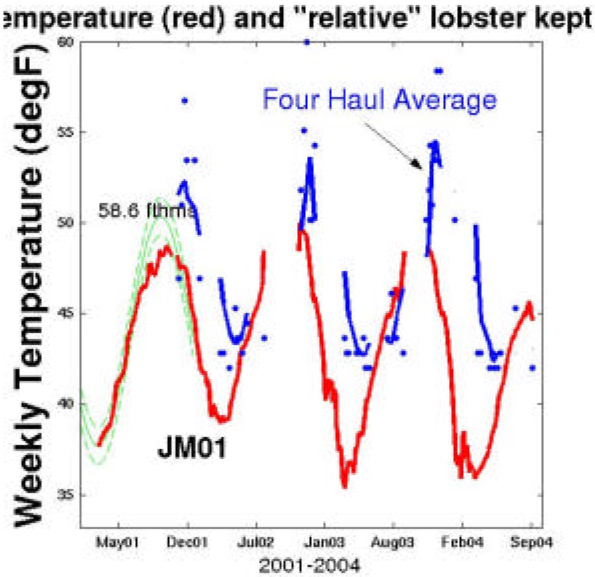


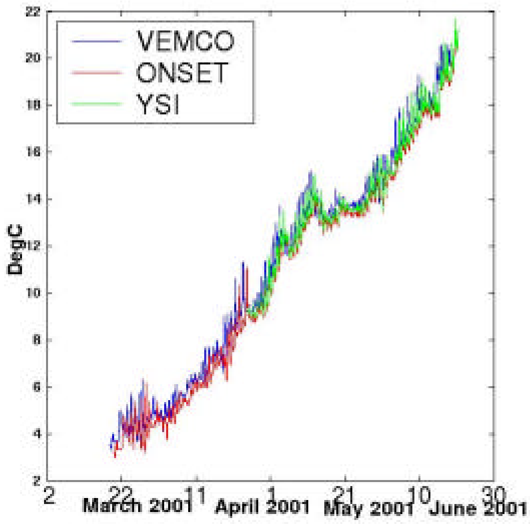
Figure 27. Attempts to overlay/compare temperature vs catch.

10. Error Analysis

What are the most important sources of error associated with eMOLT temperature data? We will address one at a time. First, given that our instrument platforms are often relocated on a regular basis, it is necessary to consider the error associated with trap movement. Since the vertical gradient of temperature for certain depths of the water column can be significant, if probes are relocated to different depths on a near-daily basis then one should expect associated temperature signals to be seen in the time series records. What are the magnitudes of these signals? In general, the vertical gradient of temperature in our study area is small. We can quantify how small this gradient is with a close look at data from the more traditional forms of measurement such as the Conductivity, Temperature, and Depth recorder (CTD). In June of 2003, for example, 250 CTD casts were conducted on the cruise. Here, off the coast of Maine where the topography is most variable, in certain times of the year one may often detect as much as 1 degC change in temperature over the bottom 20% of the water column. Since we allow for a 5% water column depth change for any particular site, we may be introducing a "trap movement error", therefore, on the order of 0.25 degC (at most). This is larger than the reported accuracy of the probe (0.1 degC) but still significantly smaller than the dominant signal mentioned earlier of several degrees.

Given that several probes deployed by AOLA recently included a pressure sensor, it is now possible to quantify temperature's depth-dependent relationship on the shelf edge. This is a very dynamic environment where a trap might be exposed to cold Canadian ice melt in one depth and, if moved a few fathoms deeper, end up in warm tropical water. We can now calculate the statistics on temperature change as a function of depth change. If we take the record referred to in Figure 24 above, for example, we see that the temperature changed on average -0.02 degF per meter. This figure obviously depends on the season and the location. David Spencer's recent deployment, for example, recorded a -0.03 degF per meter value. Given that these sites are typically in the range of 300 meters, if the participants are moving traps around by 5% of the water column, the error associated with "trap movement" is approximately 0.3 degF, similar to the figure estimated above.

The second most important source of error is probe-to-probe temperature bias? We have looked at this potential error extensively and reported results on "www.emolt.org". There is a section in the "Getting Started Manual for Administrators" called "Probe Comparisons/Calibrations" with a history of test results from both the field and in the lab. Example figures are presented below which compare various probe types (Figure 28), probes of one type (Figure 29), and probes in an ice bath (Figure 30). As of this writing, we have detected only one probe out of several dozens that preformed unsatisfactorily. As noted in the methods section above, our methods of checking for biases has been continually refined and, after multiple consultations with the manufacturer, we have adjusted the procedure for testing accuracies of these probes.



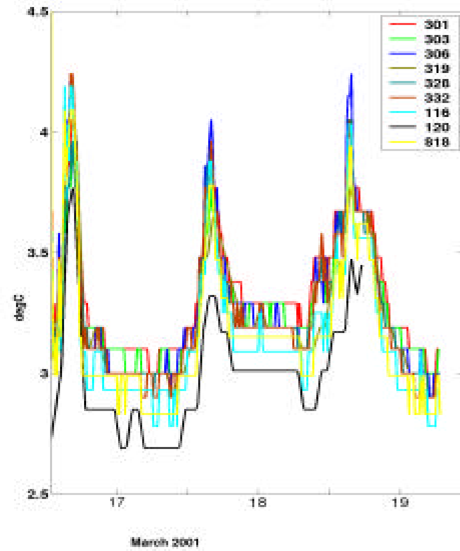


Figure 28. Example of comparing probe types.

Figure 29. Example comparison of probes.

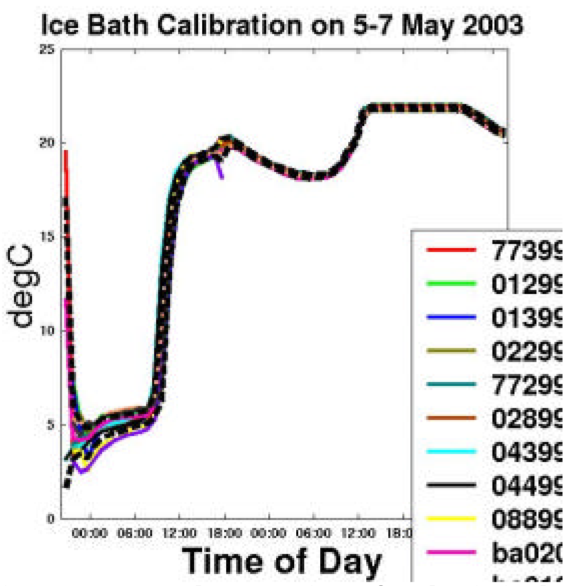


Figure 30. Example comparison of probes in ice bath.

We have also recognized the importance of time conventions (i.e. distinguishing DST and EST time stamps). We have settled on using EST as the eMOLT convention since most probes are initialized during the winter months.

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Partnerships

The eMOLT temperature project is truly a collaborative effort. In addition to the administrators listed in the "participants" section above, there is also the lobstermen who actually conduct most of the field work (Appendix I),

Impacts and applications

As noted in final reports of earlier phases of eMOLT, one could say that NOAA is the primary "end-user" of the eMOLT project. As NOAA and Ocean.US prepare for the implementation of a nation-wide ocean observing system (OOS), they will begin with an integration of existing observational networks. What better place to begin than with the individuals who already spend their days at sea, have the biggest stake in preserving the resource, and are the most knowledgeable of the local waters? If NOAA intends to invest in the future of our coast, these individuals need to be recognized, recruited, and supported for their efforts. NOAA needs to look towards the many organizations of fishermen such as local lobstermen associations. GoMOOS, a prime example of a regional OOS, has done well in this respect by catering to the industry's need. They have been present at many of the forums where fishermen congregate, have listened to their needs, and have recognized eMOLT as a means to supplement the data they collect.

Related Projects

The project that is most clearly related to all phases of eMOLT is the Gulf of Maine Ocean Observing System. In fact, one of the primary objectives of eMOLT is to supplement the GoMOOS operation and contribute to their pioneering work in developing a regional system. However, we are also developing a relationship with the US Coast Guard who maintain more fixed moorings along our coasts than any other organization. As a pilot/demonstration project, we have provided local USCG buoy tenders with a few temperature probes which they have attached to deep moorings in Cape Cod Bay. These moorings remain fixed for approximately two years after which they will be recovered. We also have close working relationships with both the Division of Marine Resources (Maine) and the Division of Marine Fisheries (Mass). We have exchanged temperature datasets with both these state agencies. We stay in close touch with the efforts of the Lobster Institute, the Lobster Conservancy, and the UNH Lobster Lab. Our Canadian partners, the Fishermen and Scientist Research Society, have a similar program with the Nova Scotian lobstermen. While we have yet to merge our datasets, the discussions to do so are underway. Finally and most recently, the multiple “ventless trap surveys” funded by a variety of institutions in the last few years are providing additional platforms for eMOLT temperature probes.

Presentations

The “training sessions and meetings” page of the emolt.org site lists the dozens of seminars and meetings that have been conducted over the years where eMOLT data has been presented. The most well attended of these meetings by a large variety of people with multiple backgrounds are the Mass Lobstermen's Annual Weekend and the Maine Fishermen's Forum.

The scientific aspects of the eMOLT drifter project have been presented on multiple occasions to in-house personnel at the Northeast Fisheries Science Center, the Woods Hole Oceanographic Institution, and participants of the semi-annual workshops of the

New England Numerical Ocean Modelers as documented at: http://sole.nefsc.noaa.gov/~jmanning/circ/nenocm.html.

Published reports and papers

The publication of eMOLT data in this project and in all phases of the eMOLT project has been distributed on the web. At least one scientific journal article, "Temperature dependence of cardiac performance in the lobster *Homarus americanus"* is at the time of this writing in press for the Journal of Experimental Biology. Mary Kate Warden, the lead author from U. Virginia, uses eMOLT data as example of the temperature ranges the animal is exposed to in the wild. The eMOLT project has been written up in the press many times as documented at the “eMOLT in the News” site linked from the homepage emolt.org.

Images

In addition to the images imbedded throughout this document, there are hundreds on the emolt.org website. Animated maps of bottom temperature fields evolving over time with wind vectors overlaid are provided as well.

Future research

Having successfully developed a workable protocol and a network of mariners to deploy and recover these instruments, there are now opportunities to conduct a variety of research on bottom waters of the Gulf of Maine. The hope is to now turn more attention to the numerical simulation of the processes that have been observed. From the very beginning of eMOLT development, the primary objective in collecting a broad range of data is to help initialize, assimilate, and validate various coastal ocean models in the region. This type of activity has already been underway at the University of Maine Orono, the University of Mass at both Dartmouth and Boston, the University of New Hampshire, Dartmouth College, and the Woods Hole Oceanographic Institute where modelers have used eMOLT drifter data to examine model performance (He et al., 2005).

Appendix Ia. Sample logsheet used in the first few years of eMOLT.

eMOLT Temperature Probe Logsheet

Name: ________________Vessel:____________Trap Type:_______Site Code_____Probe#:____

Location: (degrees, minutes, decimal minutes) ______________________Depth (fathom)__________

REQUIRED INFORMATION					OPTIONAL INFORMATION (only electronic entry accepted)			
Date	time	Location	Location	Depth	Pots/string	Keepers/string	Shorts	Eggers
Date of haul	*Time of haul*	*GPS(lat/lon) degrees, min, decimal minutes, (DDMM.M)*		*Fathom*	#	#	#	#

Appendix Ib: Information printed on the backside of the logsheet

Finding the Right Place for the Probe:

- you plan to keep the trap in the same place for as long as possible; AND
- you expect to fish every year
- is as deep as possible (30Fathom or more preferred)
- if you move the trap, do not move it more ½ mile or more than +/- 5% of original depth

Deploying the Probe:

- Secure the probe in the trap with a tie wrap to the bridge inside the trap
- Fill out a log book entry when you first deploy the trap with the temperature probe
- Fill out a log book entry each time the trap or trawl is hauled (only if a) you moved the trap or b) you plan on submitting an electronic version)

Understanding the Logbook:

Name:	Your name
Vessel:	The name of your vessel
Trap Type:	Indicate trap type: length, # parlors, # of escape vents
Site Code:	This is the identification number corresponding to a particular location where you deploy a temperature probe. It is identified by your initials followed by a sequential number.
Probe #:	The last three digits of the 6 digit serial # located on the left side of the probe
Location:	Record this information in lat/lon (GPS) in degrees, minutes, decimal minutes (DDMM.M). Location should remain constant for a particular site #.
Depth:	Record this information in Fathom. Depth should remain constant for a particular site.

Reading the Data:

- If you have your own reader, mail in the logbook page each time the probe is read (start a new logbook page when you redeploy the probe)
- If you do not have a reader, the GOMLF will contact you when it's time to send in your probe to be read.

Assn	**contact**	**Mailing Address**	**Phone**	**Email**
GOLMF	Erin Pelletier	PO Box 523 Kennebunk, ME 04043	207-985-8088	eringom
MeLA	Patrice Farrey	1 High St. Suite 5 Kennebunk, ME 04043	207-985-4544	patrice@
MaLA	David Casoni	134 Halfway Pond Rd, Plymoth, MA 02360	508-224-3038	lobsterte
DELA	Jeremy Cates	RR 1 Box 4700, Sedgwick, ME 04676	207-359-8025	catesjere
AOLA	Bonnie Spinazzola	Adams Rd, Candia, NH 03034	603-483-3030	bonnie@
NEFSC	Jim Manning	166 Water St, Woods Hole, MA 02543	508-495-2211	James.m

Appendix II. Individuals who have contributed temperature data to the eMOLT database as of 2006.

Maine Lobstermen Association:

Alley Ricky
ANDERSON Billy
Baines Bob
Bridges Tom & Barbara
Fifield
Carter Jon
Carter Shane
Carver Dick
Chadwick Darryl
Day Jason
Doliber Ben
Flanigan Peter
Fernald Bruce
Gilliam Ray
Gamage Arnold Jr.
Folger Sean
Ingalls Robert
Johnson David
Kasaei-Fard Shahram
Mclain Brian
MacVane Tom
MerrillIII JOHN
Miller Dan
Newcomb Randy
NuddJr Bob
Post Woody
Smith Jay
Sprague George
Stover George
Tarbox Brian
Thomson Mattie
Thomas Elliot
Tripp Jim
Wells Mark
White Pat
Whitener Zach

Mass Lobstermen Association:

Alberts Jeff
Brown Alex
Carroll Emmett
Carver John
Casoni Dave
Dauphinee Fred
Doherty Bill
Davis DJ
Grey John
Haviland John
Jesse Todd
Kandrick David
Keane Stephen
Marcella Bob
Martin Bobby/Rob
Mason Phil
Mason Pete
Mike O'Conner
Oehme Kurt
Ryan Skip/Chris
Sauvageau Therese
Sawyer Arthur/Sooky
Souza Billy
Tufts Mike
Tupper Mike

Downeast Lobstermen Association

Backman Ralph
Bridges Leroy
Brewer Russell
Cates Brian
Cates Jeremy
Chipman John Sr.
Dassatt Mike
Day Walter
Farrin Clive
Faulkingham Michael
Lemieux Norbert
Lemieux Nick
Robbins Stevie

Atlantic Offshore Lobstermen Association:

Bennett Paul
Campanale RobRoy
Colbert Bob& Denny
Cote Bro
Mataronas/Buffington
Gary
Moore Grant
Palombo Marc
Peabody John
Shafmaster Jonathan
Spencer David
Violet Jim

Mass DMF:

Tracy Pugh
Barber Julie
Glenn Bob
Estrella Bruce

Other:

Marchetti Mike (RILA)
Landers Don (NU)
Angell Tom (RI-DEM)
Lazzari Mark (DMR)
Nelson Dave(NMFS-Ct)
Davies Ed (NMFS-RI)